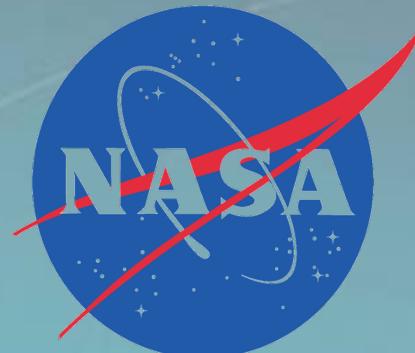


Seasonality of biases between CMAQ and OMI tropospheric NO_2 columns over the eastern and central US.

Xinzhou Huang, D. J Allen, and T. Canty (UMCP)

K. E. Pickering (NASA-GSFC)

R. Pinder and K. Wyat Appel (EPA)



Description of Problem

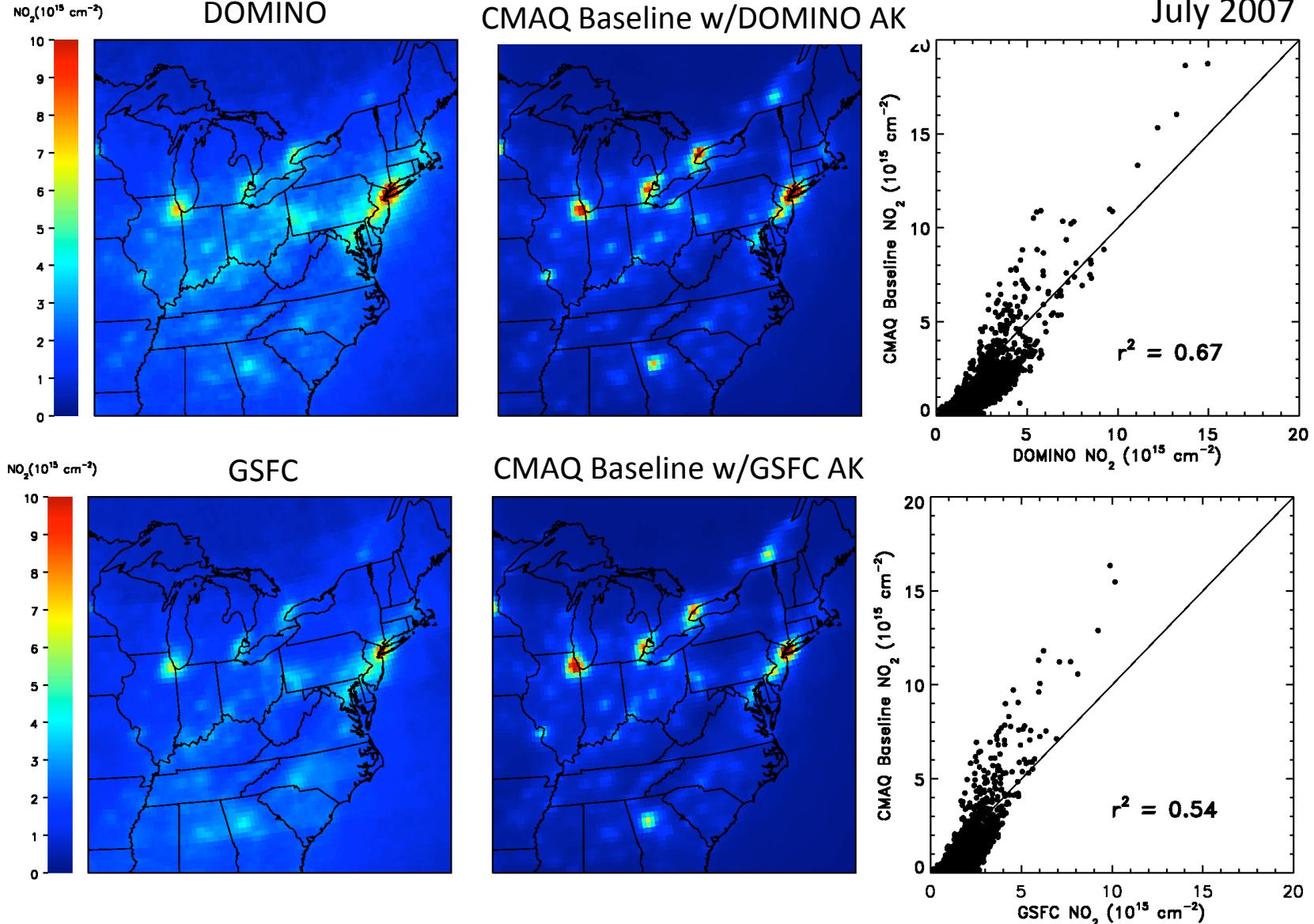


Figure 1: Comparison of satellite observations of tropospheric column NO₂ (left panels) to output from a baseline CMAQ model run convolved with the satellite averaging kernels (middle panels). --Canty, T., et al, to be submitted 2014.

Description of CMAQ simulations

➤ **PHASE** (Public Health Air Surveillance Evaluation, Appel et al., 2011)

- 12km CMAQv4.7.1 simulations
 - PHASE noL: 2005 - 2008;
 - PHASE wL: Jun 2006 – Dec 2008

$$\text{PHASEwL} = \text{PHASEnoL} \times (\text{GMIwL} / \text{GMInoL})$$

(--Allen, D., et al., 2012; Duncan, B. N., et al, 2008)

➤ **AQMEII** (Air Quality Model Evaluation International Initiative, Rao et al., 2010)

- AQMEII^{noL}: Jan 2006 – Dec 2006
- AQMEII^{wL}: **JJA 2006**

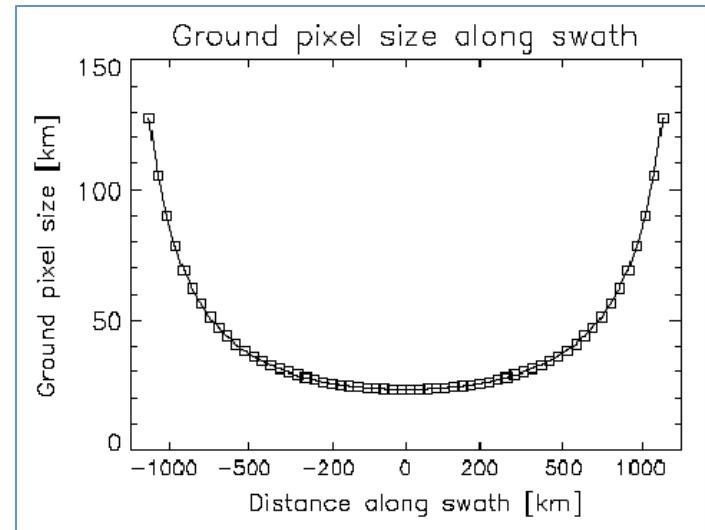
Comparison Methodology

➤ OMI(GSFC) Retrievals

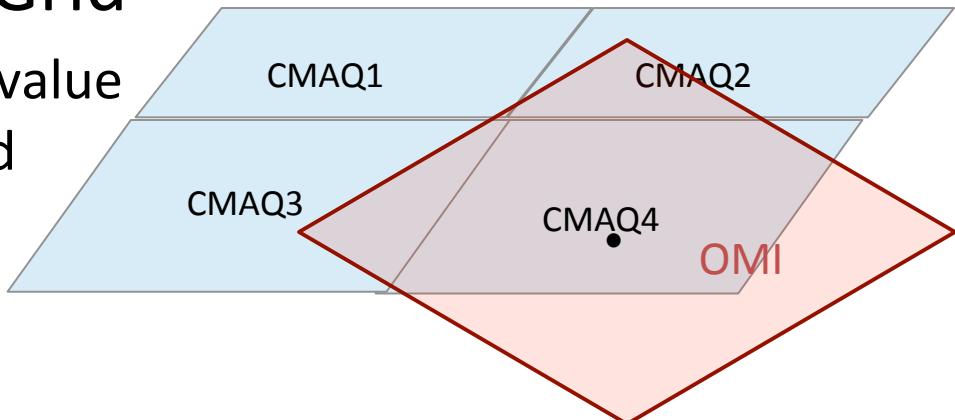
- 24 out of 60 OMI retrievals along swath are extracted at the closest to nadir position, 12 on each side;
- Exclude pixels with geometric cloud fractions in excess of 30%;
- Use retrievals when vcdquality and xtrackquality flags are both good;

➤ OMI retrieval on CMAQ Grid

- For simplification, we assign the value of OMI retrieval to the CMAQ grid where OMI pixel center locates.



The pixel-size in the swath-direction increases from $13 \times 24 \text{ km}^2$ (exact nadir position) to $13 \times 128 \text{ km}^2$ at the most outer swath-angle (57°). Source: <http://www.knmi.nl/omi/research/instrument/characteristics.php>.



Comparison Methodology

r = missing ratio profile vector (CTM);

w = scattering weight vector (RTM, from OMI);

I = identity vector ; \bullet = dot product (denotes vertical integration)

$$\text{VCD} = \text{SCD} / \text{AMF}$$

$$AMF = AMF_G \int_0^{\infty} r(z)w(z)dz$$

	Model (CMAQ) _sub M	A priori Climatology _sub C	OMI
Mixing-ratio profile vector	r_M	r_C	$r_C S / S_C$
Slant Column	$S_M = w \bullet r_M$	$S_C = w \bullet r_C$	S
Vertical Column	$V_M = I \bullet r_M$	$V_C = I \bullet r_C$	$V_{\text{OMI}} = S / A_C$
Air Mass Factor	$A_M = S_M / V_M$	$A_C = S_C / V_C$	$A_C = S_C / V_C$

(Diagram from Bucsela, et al.)

Comparison method 1:

Model as is

$$V_M$$

vs

OMI retrieval as is

$$V_{OMI} = S / A_C$$

$$V_M / V_{OMI} = V_M A_C / S, \text{ which depends on } A_C$$

Comparison method 2:

Simulated OMI retrieval of model

$$V'_M = S_M / A_C$$

vs

OMI retrieval as is

$$V_{OMI} = S / A_C$$

$$V'_M / V_{OMI} = S_M / S, \text{ is independent of } A_C$$

Comparison method 3:

Model as is

Adjust OMI retrieval, using model A_M

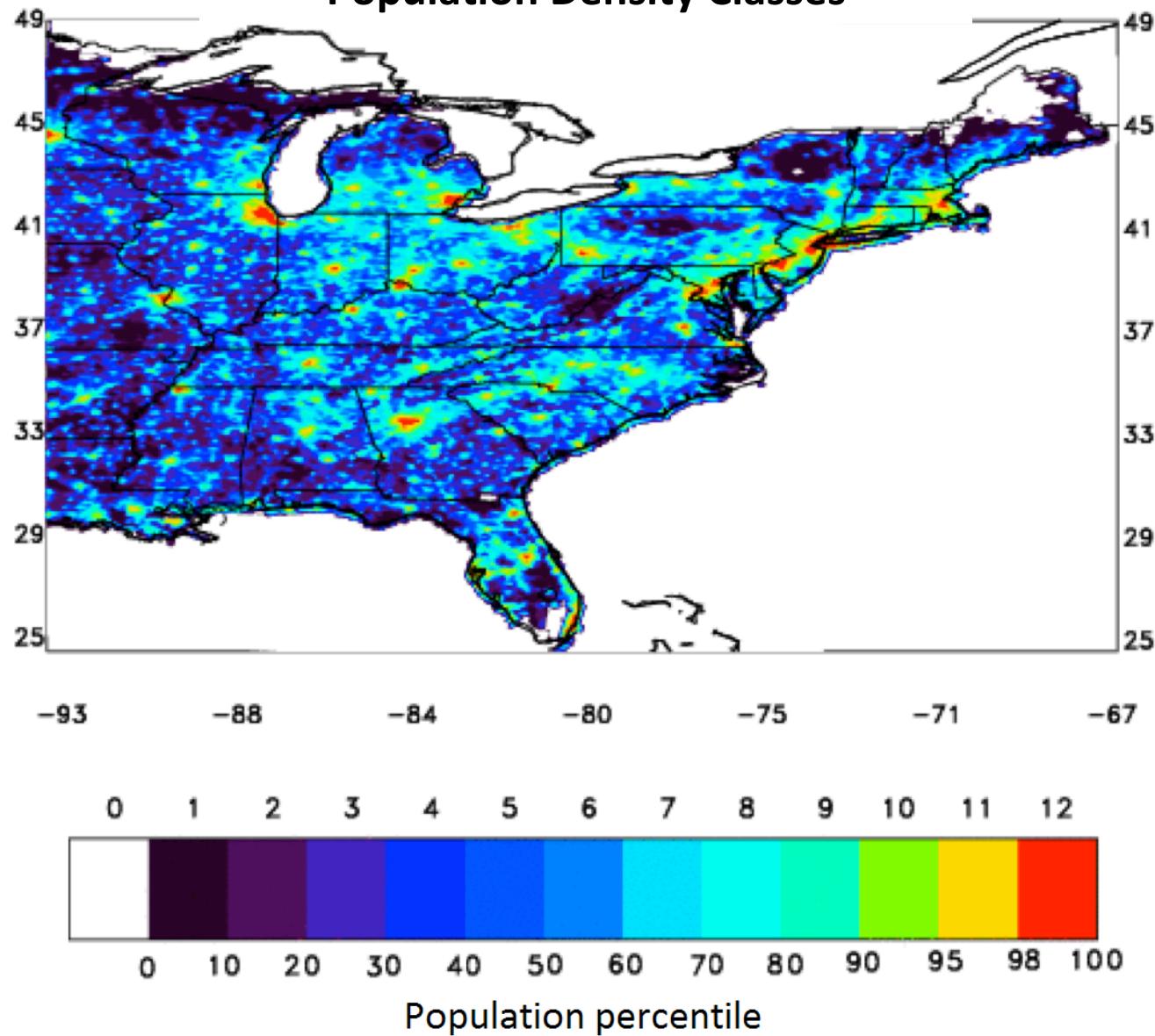
$$V_M$$

vs

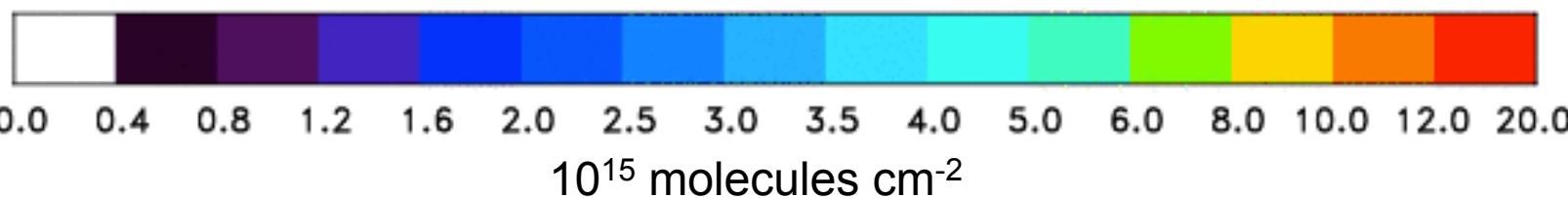
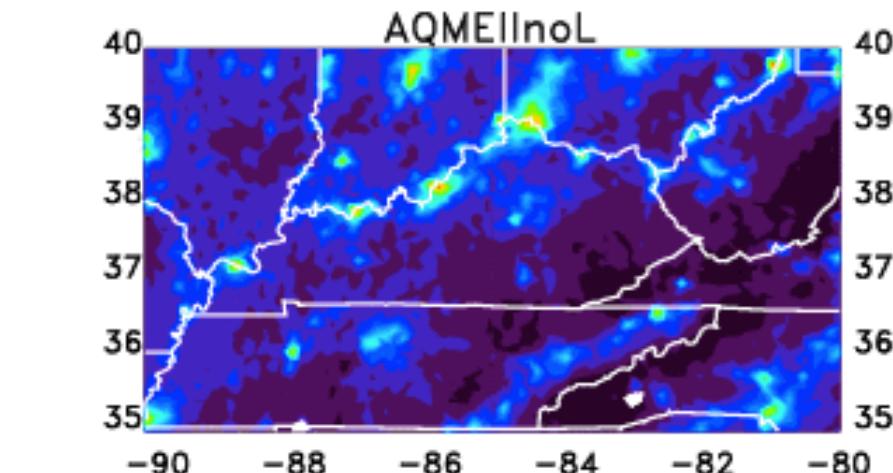
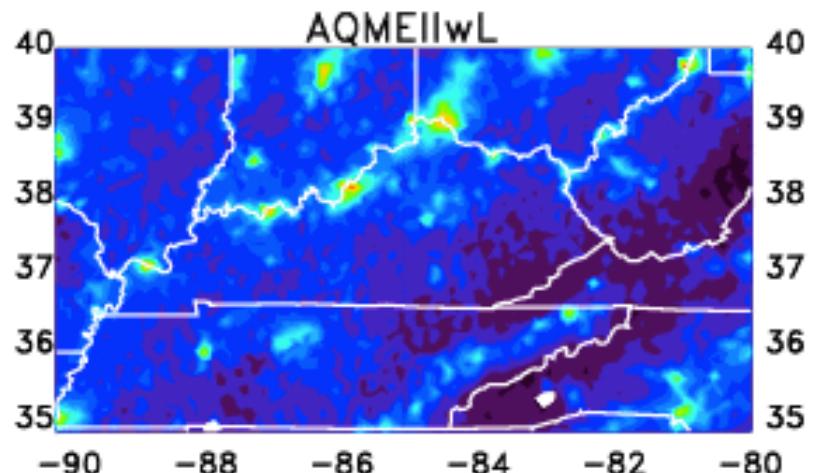
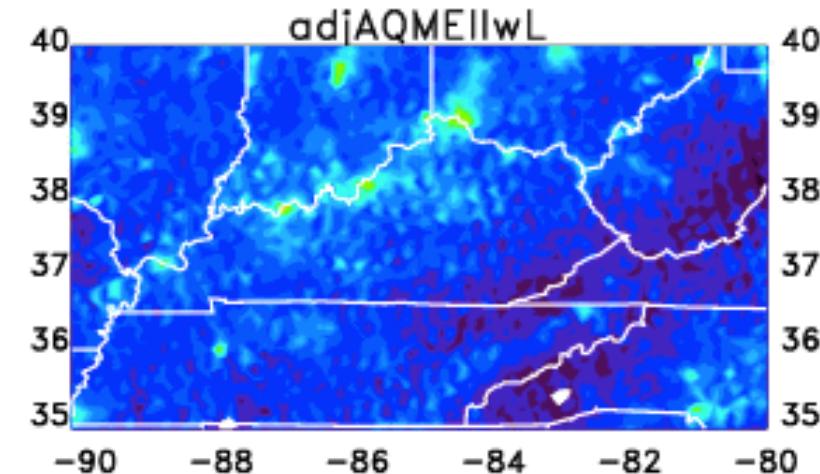
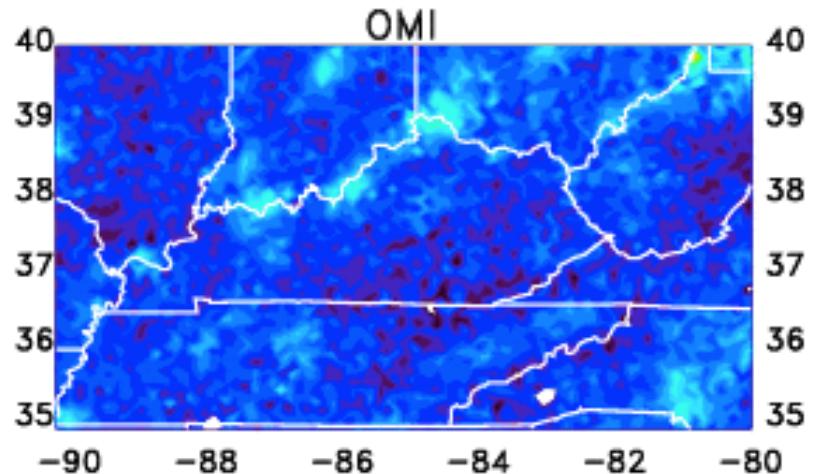
$$V'_{OMI} = S / A_M$$

$$V_M / V'_{OMI} = S_M / S, \text{ is independent of } A_C$$

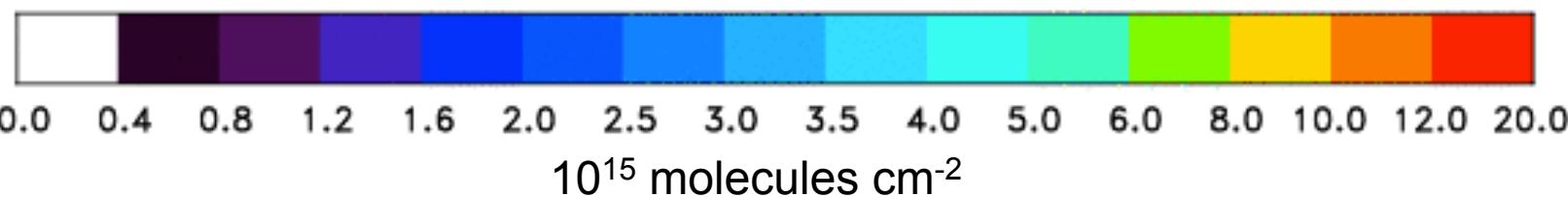
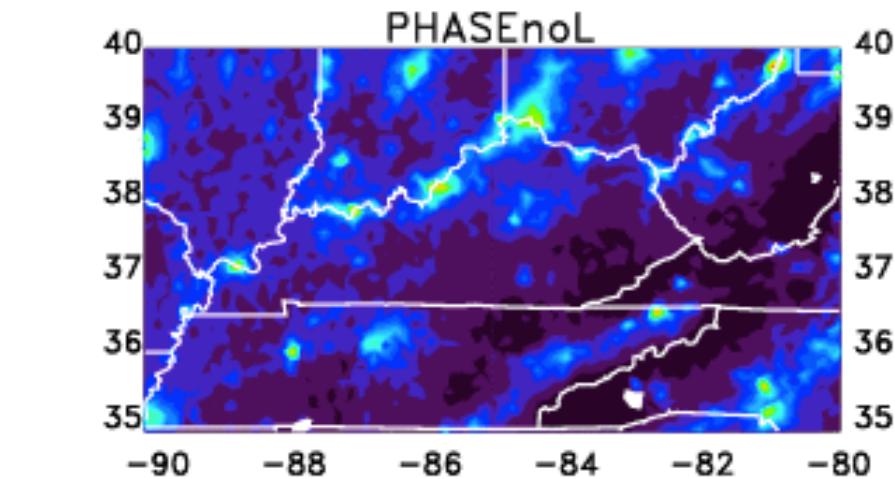
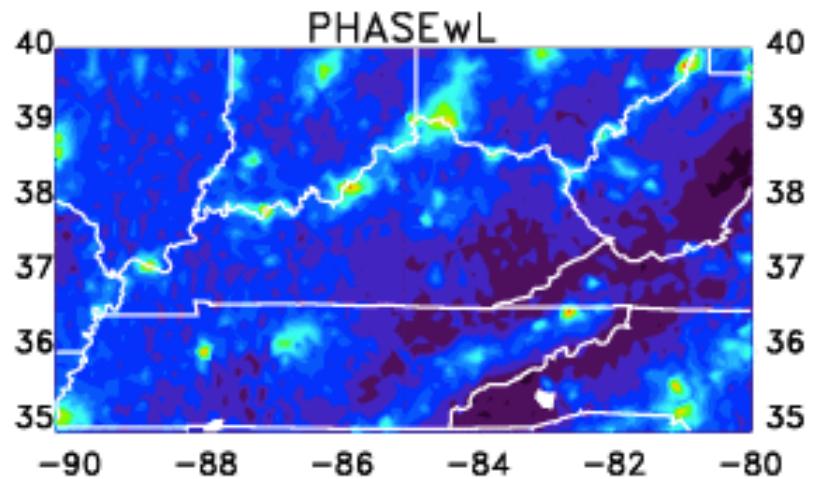
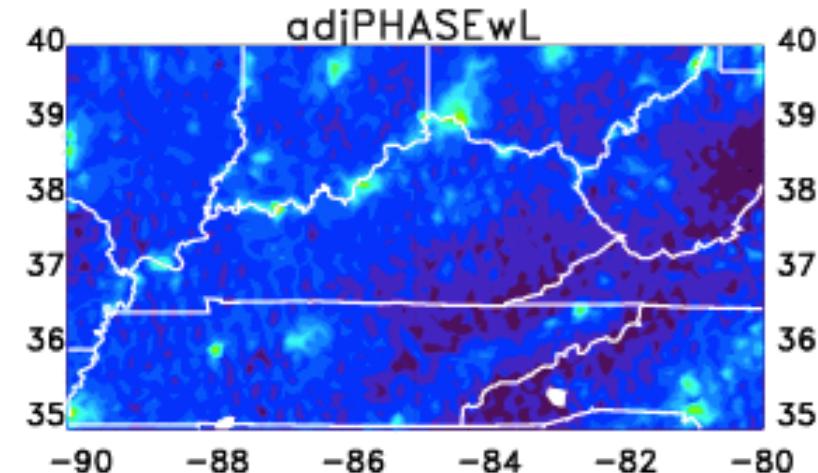
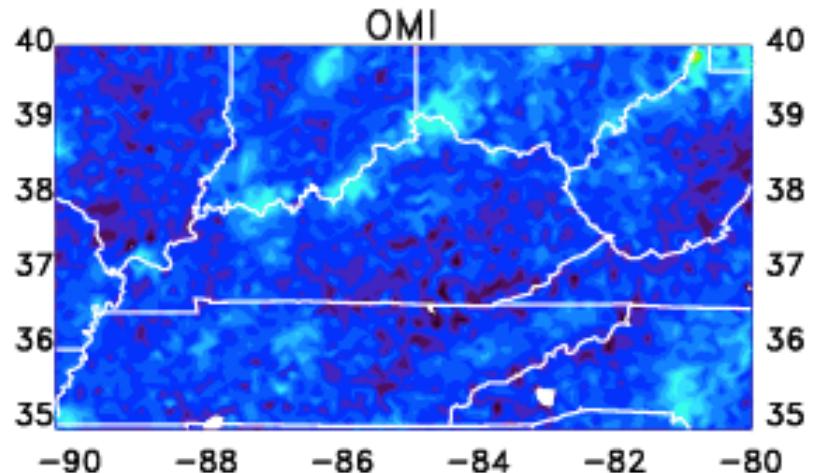
Population Density Classes



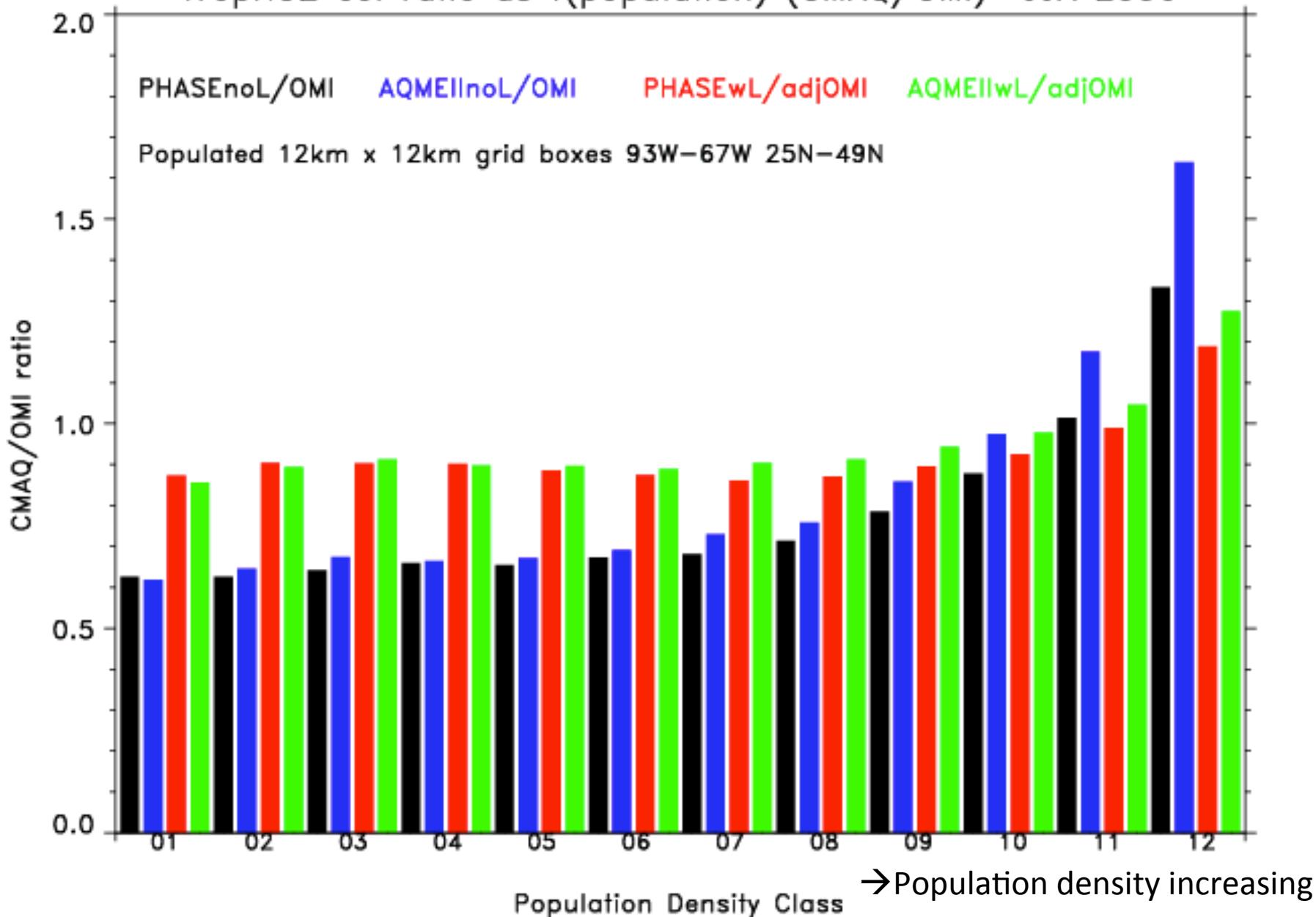
Mean Trop NO₂ column JJA 2006

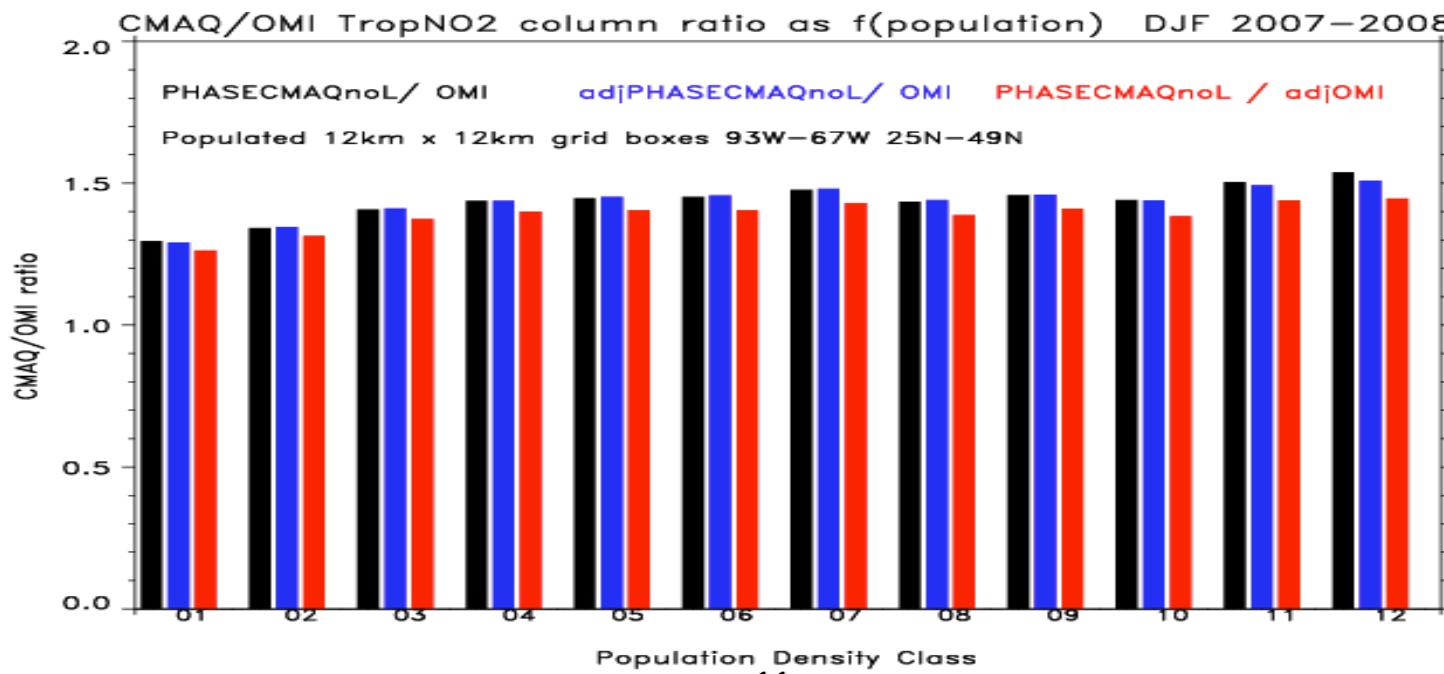
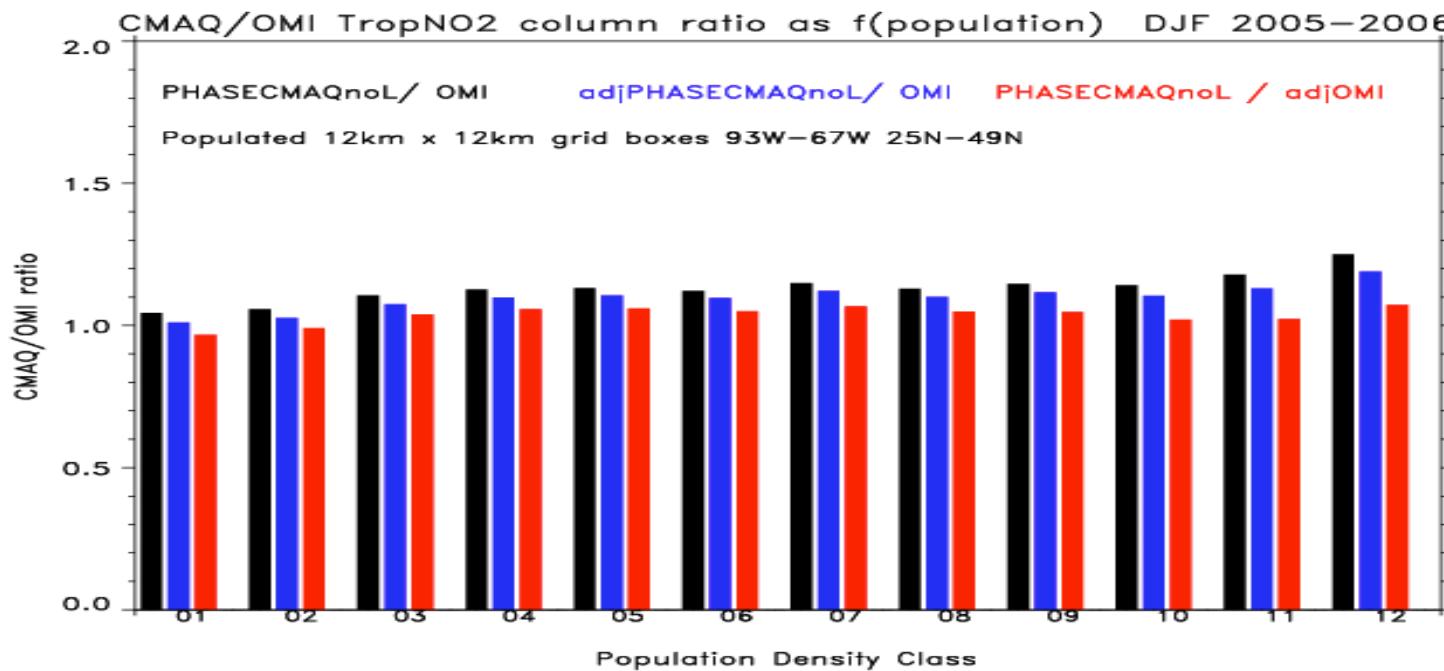


Mean Trop NO₂ column JJA 2006

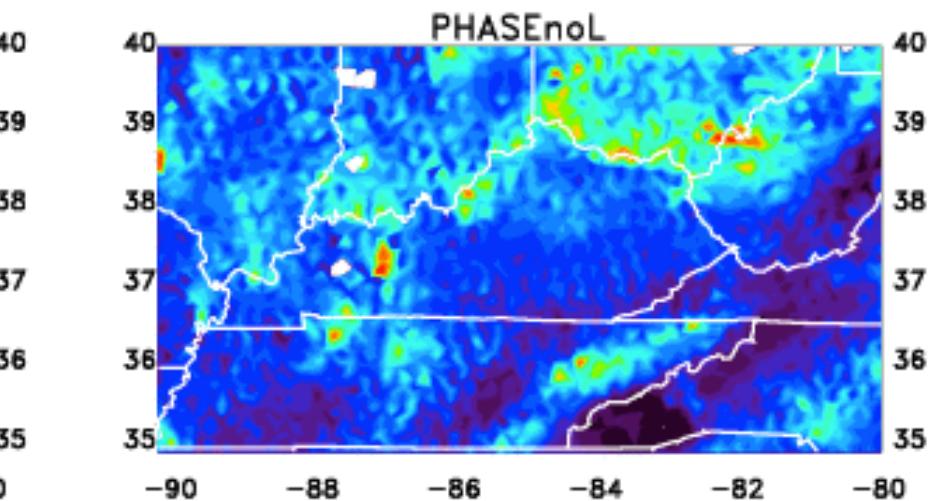
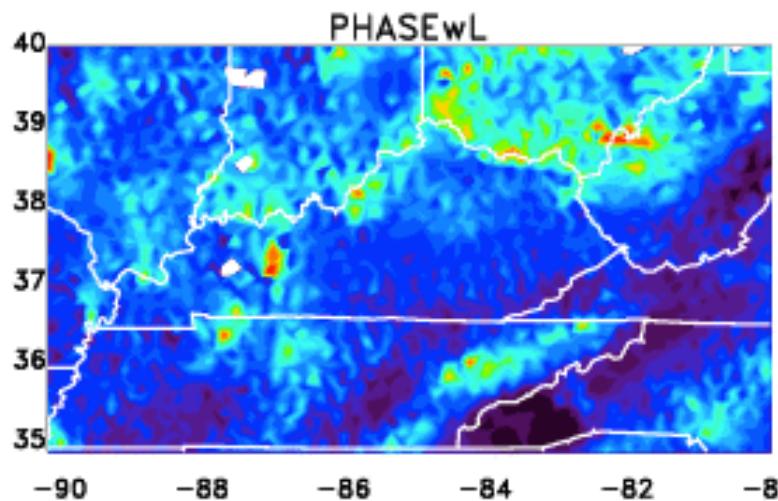
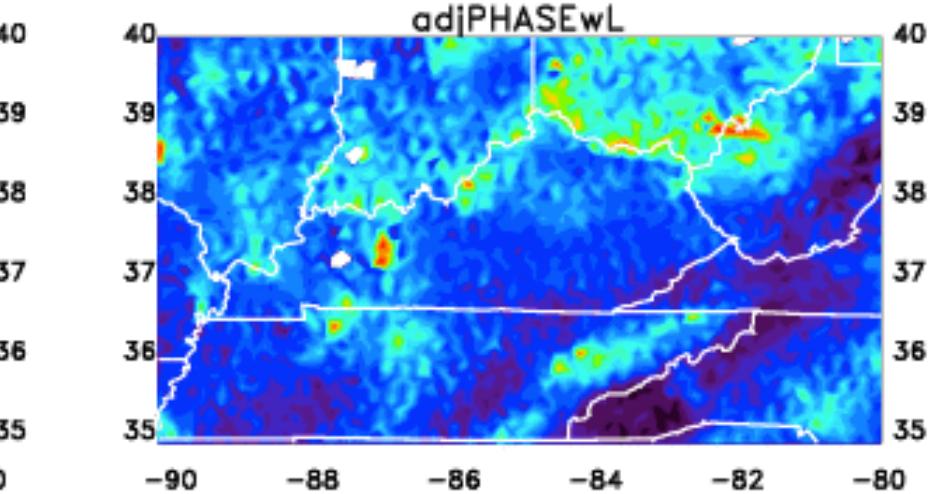
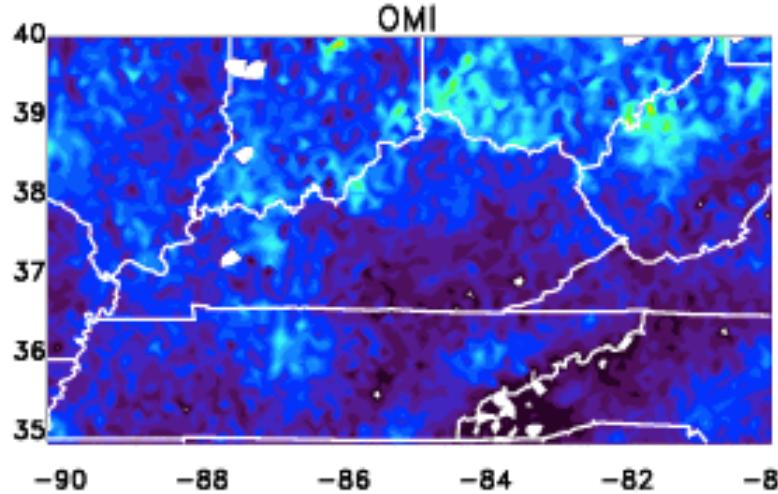


TropNO₂ col ratio as f(population) (CMAQ/OMI) JJA 2006



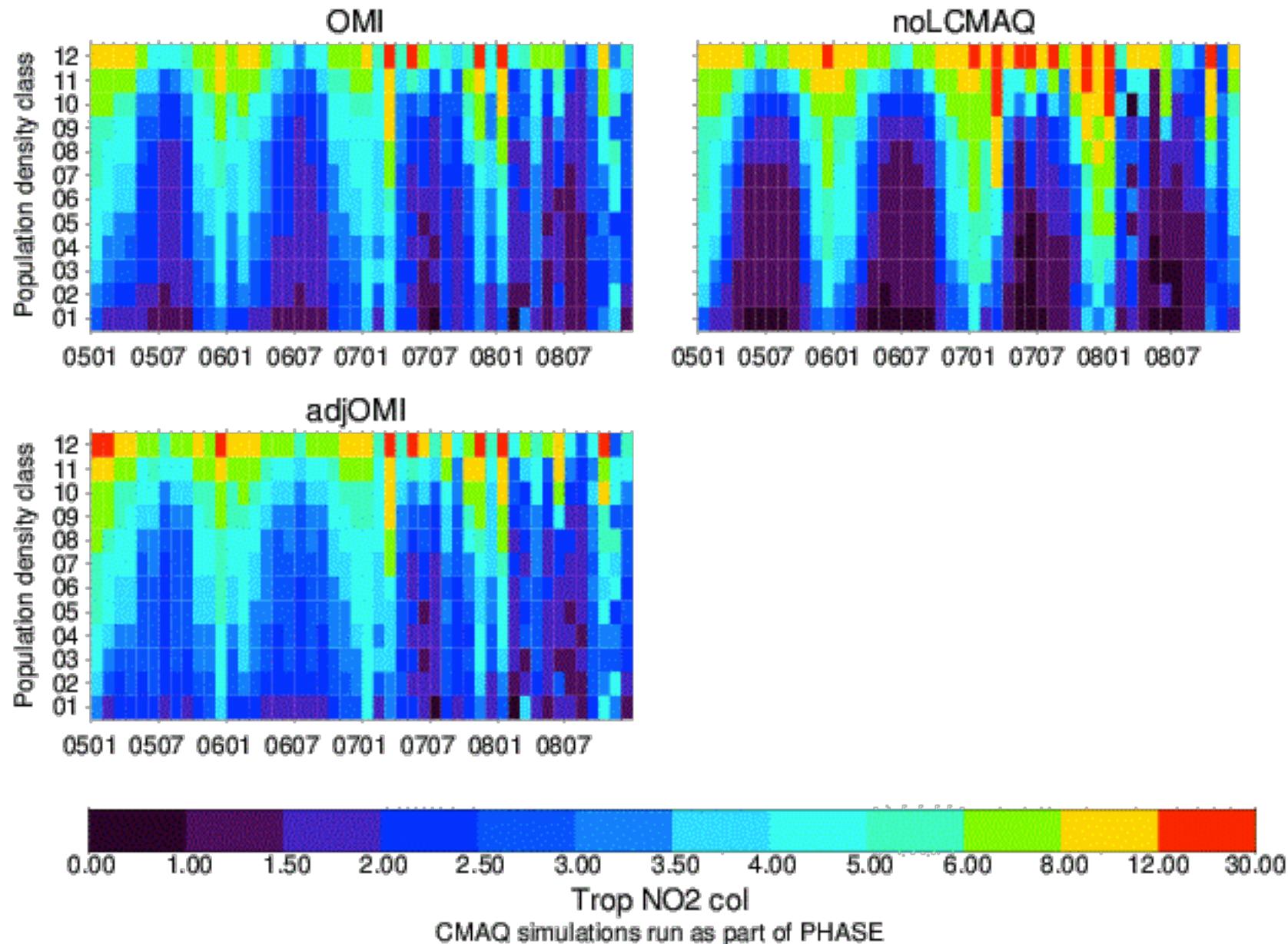


Mean Trop NO₂ column 20071201–20080229

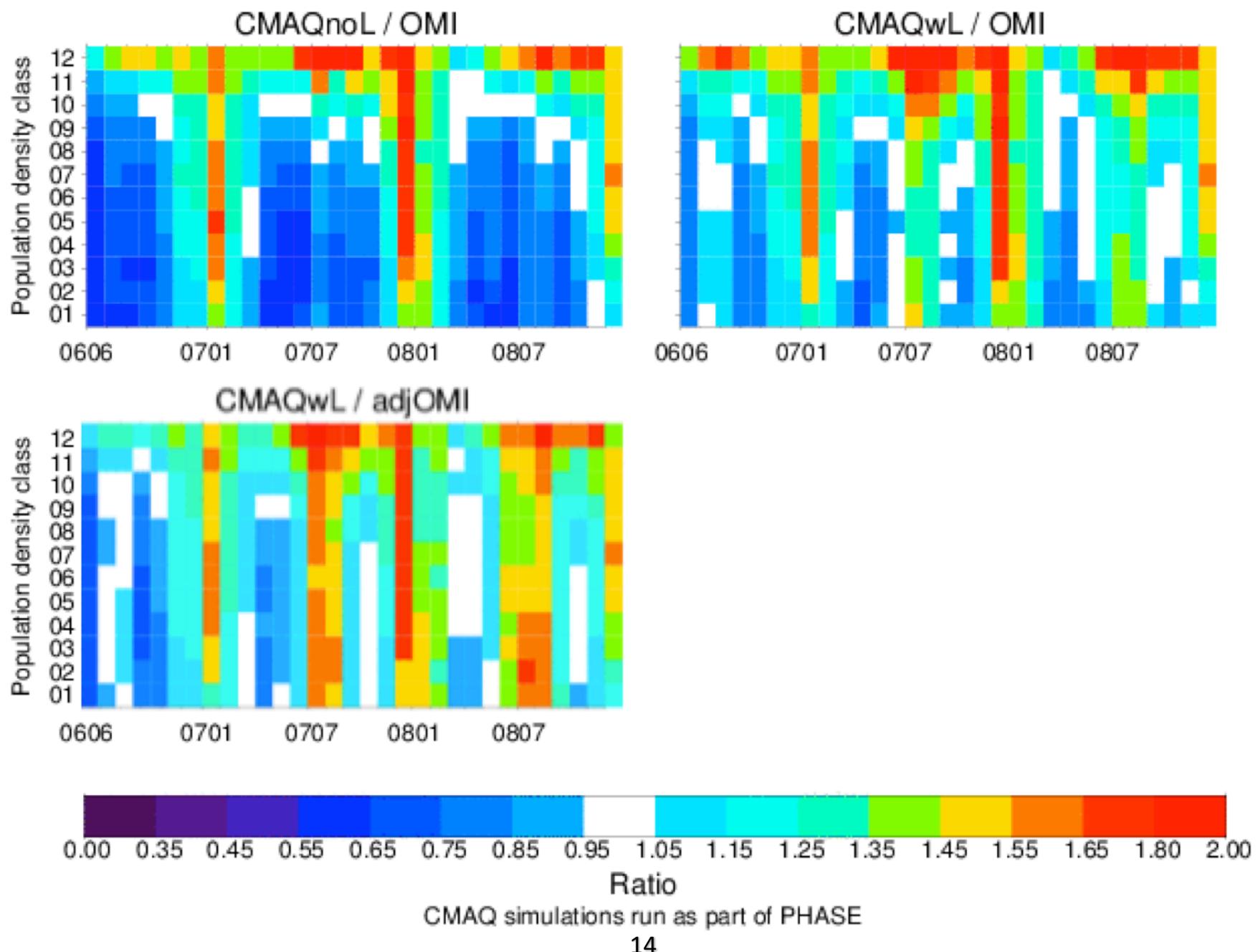


10^{15} molecules cm⁻²

tropNO2 col as a f(month, population density)



CMAQ / OMI ratio as a f(month, population density)



Summary

- In the summer, CMAQ tends to overestimate Trop NO₂ columns in urban regions and underestimate in rural regions, while in the winter, CMAQ/OMI column ratio does not vary with population density.
- Urban/Rural Trop NO₂ column differences between CMAQ and OMI are reduced when adding Lightning NO_x to CMAQ and adjusting OMI using CMAQ AMF. Lightning NO_x contributes similar amount to the NO₂ columns of rural and urban areas, which will smear the sharp differences.
- CMAQ NO₂ columns increase in 2007-2008 relative to 2005-2006, while OMI retrievals capture the reducing trend of NO_x emissions in the 4 year window. Inconsistency between NEI inventories may be responsible.

Future Work

- Change gridding methodology: remapping OMI retrievals onto CMAQ grid based on the weighting methodology used in OMI L3 product.
- Based on Maryland SIP CMAQ runs (2007 & 2011) by Canty et al., recalculate NO₂ columns from CMAQ runs with: 1) reduced mobile emission by 50%, 2) reduced NOx lifetime, 3) biogenic emission shifted to MEGAN2, 4) all above, and compare with OMI trop NO₂ using the same comparison methodology.

Thank you

Description of CMAQ simulations

➤ PHASE (Public Health Air Surveillance Evaluation)

	2005-2006	2007-2008
Common points	12km CMAQv4.7.1 simulations, no Lightning, CB05 chemical mechanism, 24 vertical layers, with year specific CEMs emission data.	
Differences	-Eastern US -MM5 meteorology -2002 NEI v3	-Continental US -WRF meteorology -2005 NEI v2 (2007) -2008 NEI v1.7 (2008)

Reference: <http://www.epa.gov/heasd/research/cdc.html>, Appel, W., et al., Geosci Model Dev., 2011.

- Convert PHASEnol to PHASEwL

$\text{PHASEwL} = \text{PHASEnol} \times (\text{GMIwL} / \text{GMInol})$ (Allen, D., et al., 2012; Duncan, B. N., et al, 2008)

- PHASEwL simulations are performed from **Jun 2006 to Dec 2008**

➤ AQMEII (Air Quality Model Evaluation International Initiative, Rao et al., 2010)

- 2006 CMAQ v4.7.1 simulation, 12km, CB-05 & AERO5, WRF meteorology, **NEI 2005 v2**, including point sources with CEMs, MOBILE6 mobile emissions, biogenic emissions from BEIS.
 - AQMEII nol : Jan 2006 – Dec 2006
 - AQMEII wL : **JJA 2006**

OMI vs. CMAQ Seasonal Variation in NOx

Factors driving Trop NO₂ columns differences:

- **NOx emission**

- little seasonal variations; ~25% uncertainty

- **The chemical mechanism with NOx loss rate**

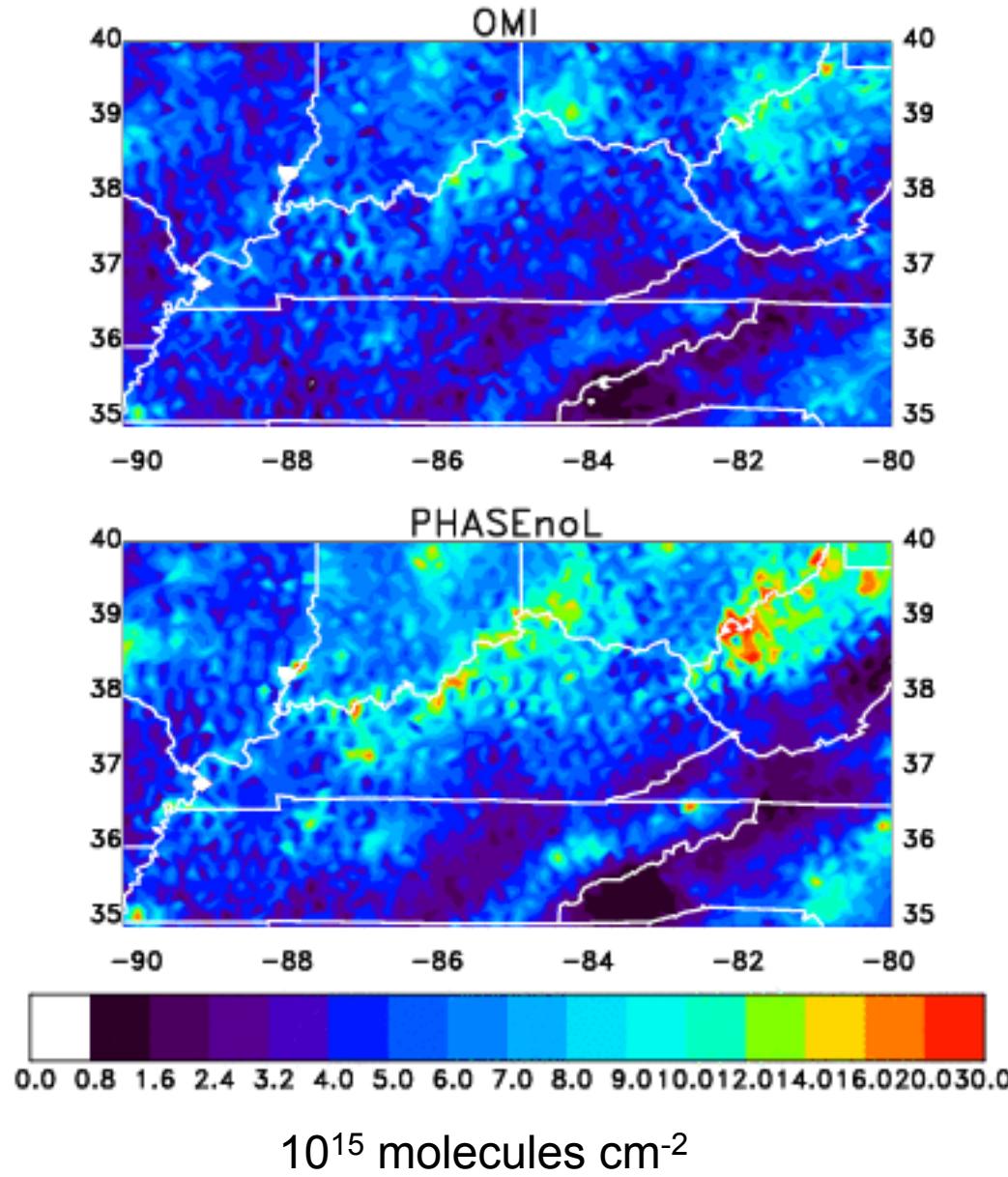
- The loss of NOx mainly occurs through formation of HNO₃ by gas-phase reaction of NO₂ with OH and by aerosol uptake of NO₂ in summer.

- **NOx lifetime**

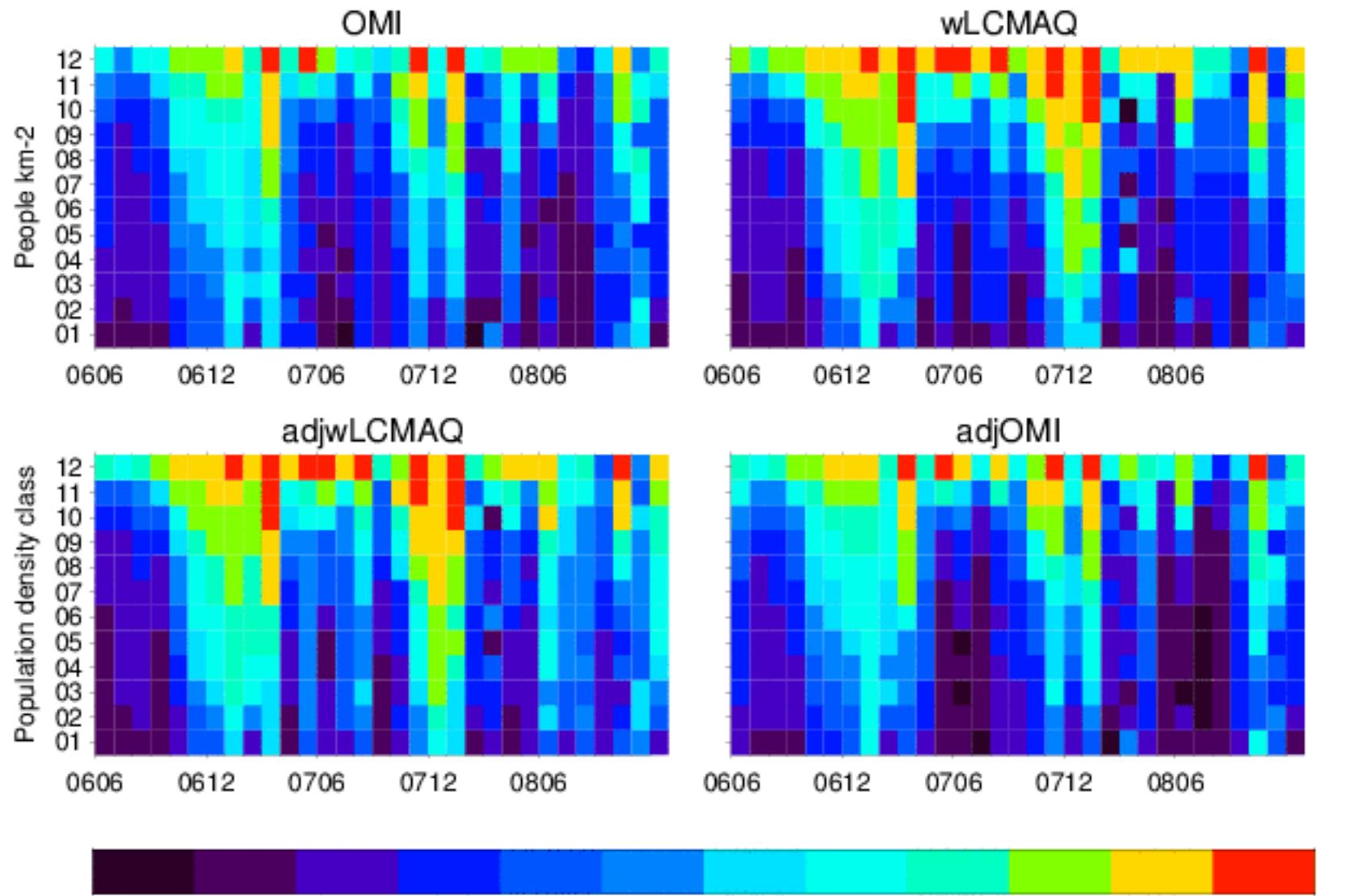
- The inclusion of faster recycling of NOx through alkyl nitrates in CMAQ/CB05 reduces OMI and CMAQ differences.

Ref: Lamsal et al., JGR 2010; Canty et al., to be submitted; Allen et al., ACP 2012.

Mean Trop NO₂ column 20051201–20060228

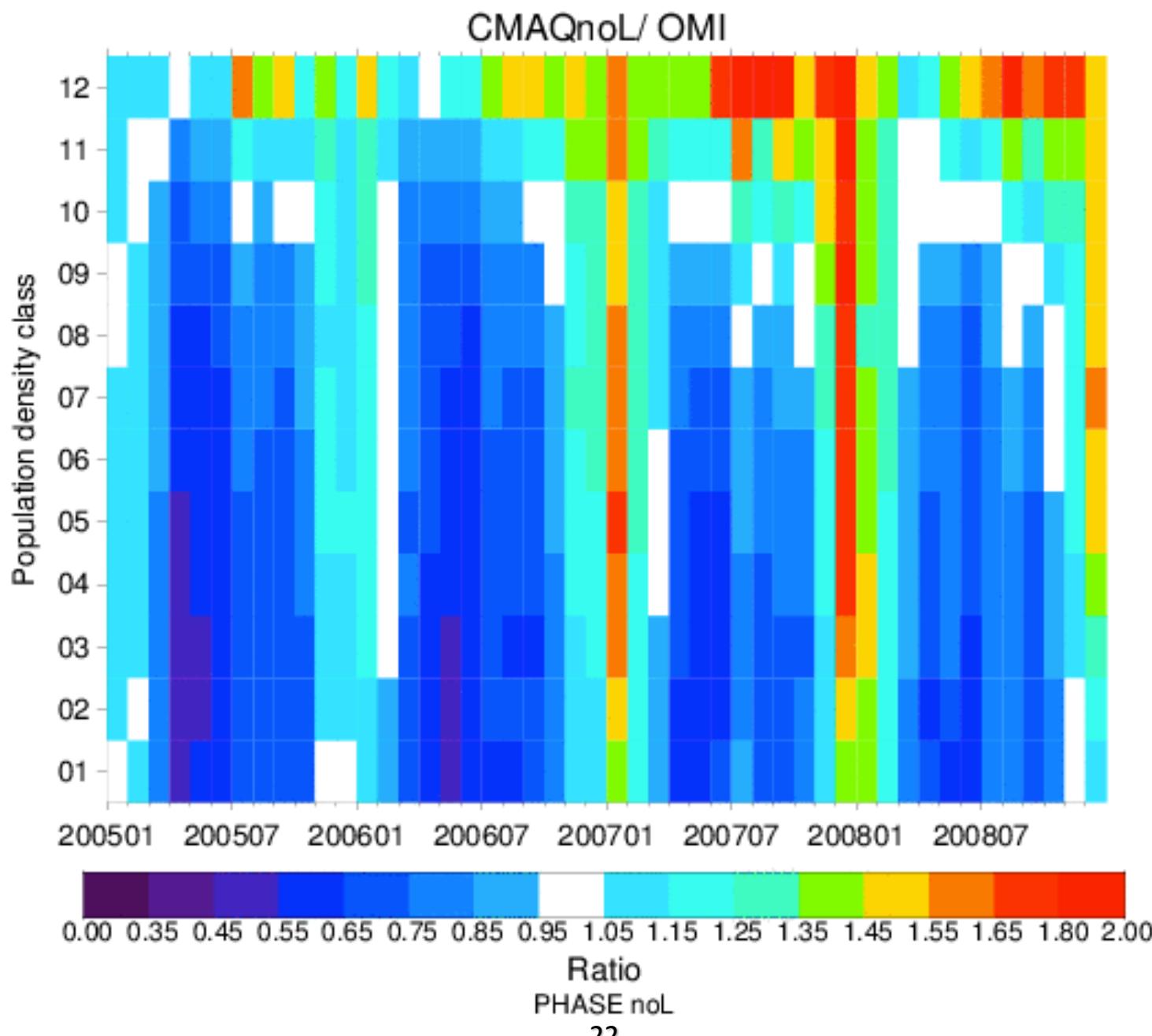


tropNO2 col as a f(month, population density)



CMAQ simulations run as part of PHASE

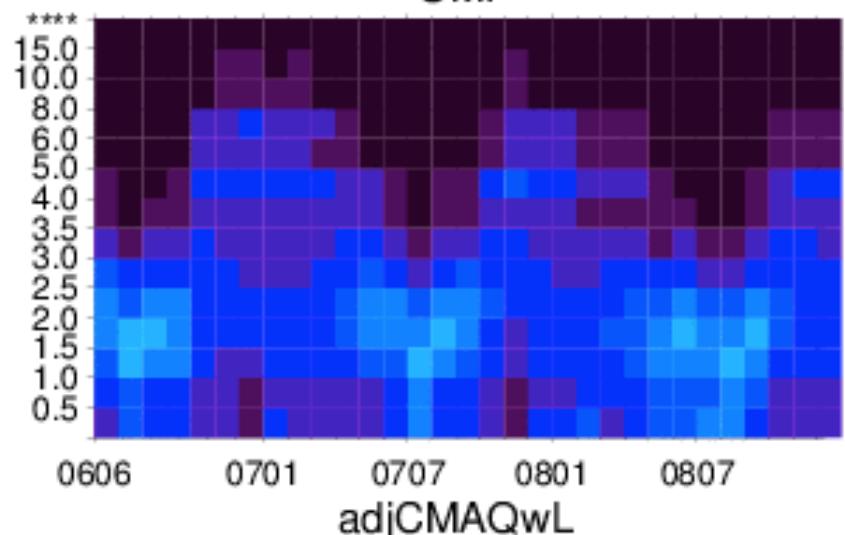
CMAQnoL / OMI ratio as a f(month, population density)



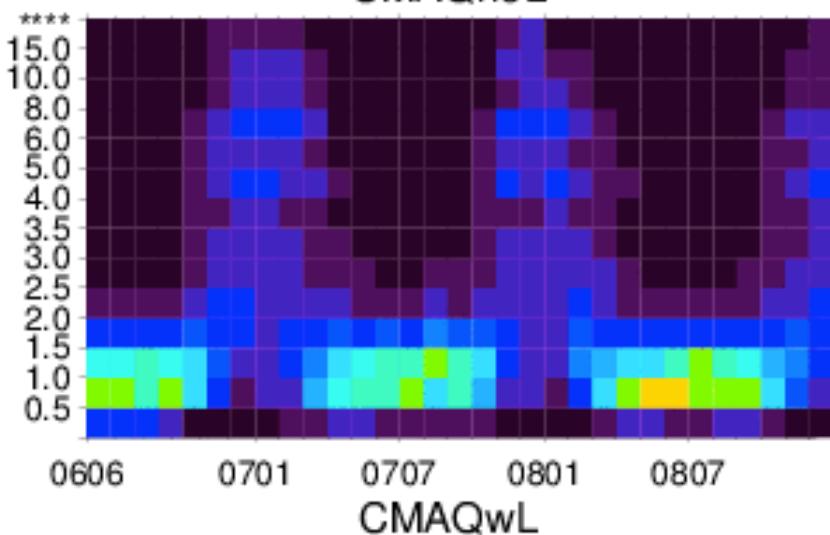
Trop NO₂ column PDF as a f(month)

OMI

TropNO₂ bins

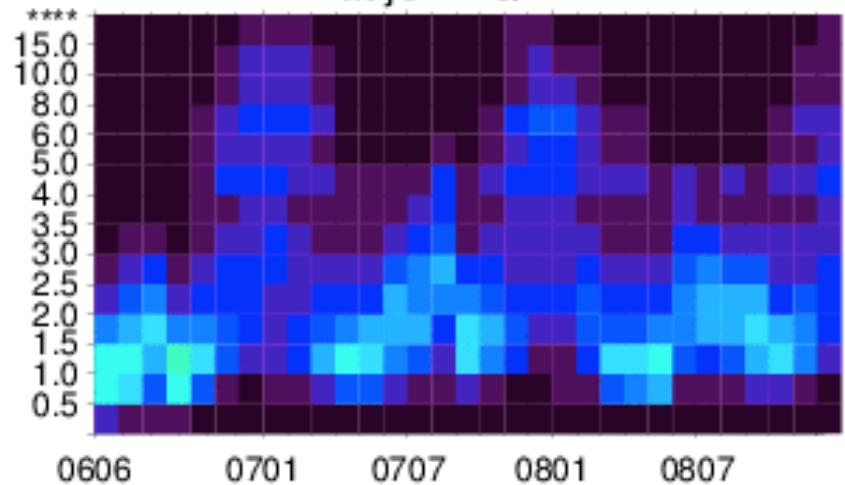


CMAQnoL

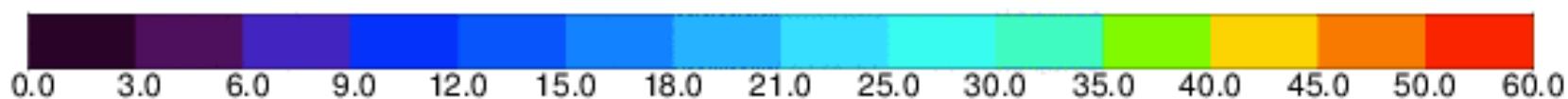
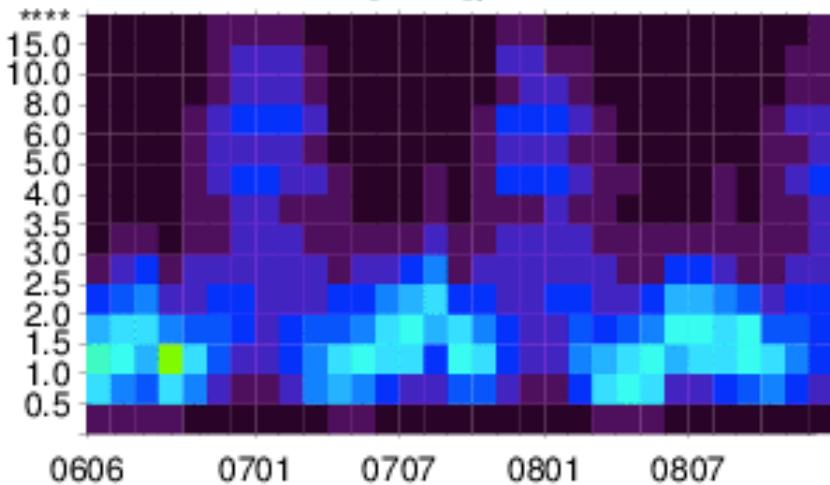


adjCMAQwL

TropNO₂ bins



CMAQwL



Percent of columns within each bin
CMAQ simulations run as part of PHASE